US 20190023115A1

(19) United States
(12) Patent Application Publication
Mackenzie et al.

(10) **Pub. No.: US 2019/0023115 A1**
(43) **Pub. Date: Jan. 24, 2019**

(54) **TWIN MOTOR DRIVE SYSTEM FOR HYBRID ELECTRIC VEHICLE**

(71) Applicant: **Ford Global Technologies, LLC**, Dearborn, MI (US)

(72) Inventors: **Kevin Mackenzie**, Canton, MI (US); **Thomas Joseph Ciccone**, Madison Heights, MI (US); **James William Dunham**, Plymouth, MI (US); **Adam Deibler**, Livonia, MI (US); **Kyle Mattinson**, Taylor, MI (US)

(21) Appl. No.: **15/656,708**

(22) Filed: **Jul. 21, 2017**

Publication Classification

(51) **Int. Cl.**

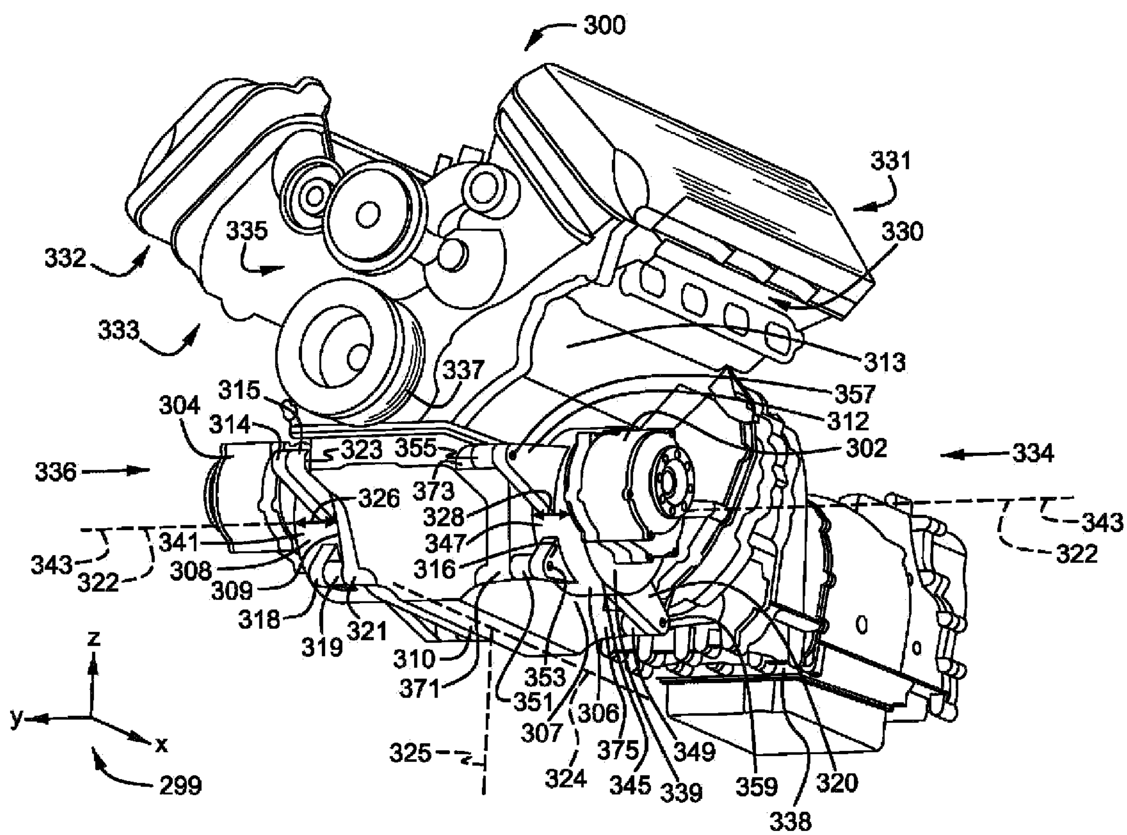
B60K 6/40	(2006.01)
F02F 7/00	(2006.01)
B60K 6/42	(2006.01)
B60K 6/26	(2006.01)
B60K 6/24	(2006.01)
B60K 6/52	(2006.01)

(52) **U.S. Cl.**

CPC ***B60K 6/40*** (2013.01); ***F02F 7/0082*** (2013.01); ***B60K 6/42*** (2013.01); *F01M 11/0004* (2013.01); ***B60K 6/24*** (2013.01); ***B60K 6/52*** (2013.01); ***B60K 6/26*** (2013.01)

(57) **ABSTRACT**

Methods and systems are provided for a hybrid electric vehicle including a front-wheel drive system and a rear-wheel drive system. In one example, the rear-wheel drive system includes an internal combustion engine configured to drive rear wheels of the vehicle, and the front-wheel drive system includes a first electric motor and a second electric motor mounted directly to opposing sides of the engine. The first electric motor is coupled to a first reduction gearbox to drive a first front wheel of the vehicle, and the second electric motor is coupled to a second reduction gearbox to drive a second front wheel of the vehicle.



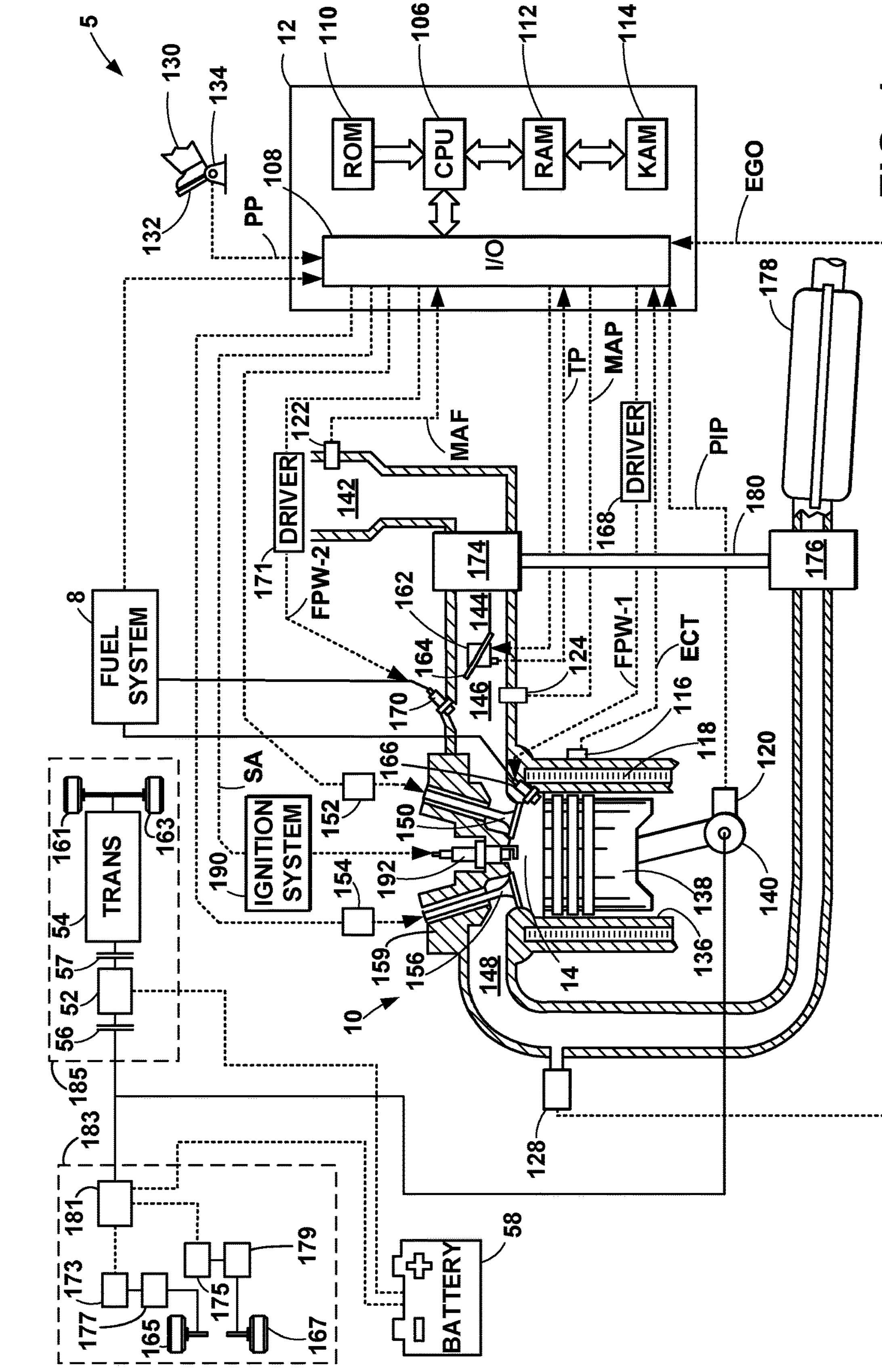

ROM
CPU
RAM
KAM
I/O
PP
EGO
MAF
TP
MAP
DRIVER
DRIVER
PIP
FPW-2
FPW-1
ECT
SA
FUEL SYSTEM
IGNITION SYSTEM
TRANS
BATTERY

FIG. 1

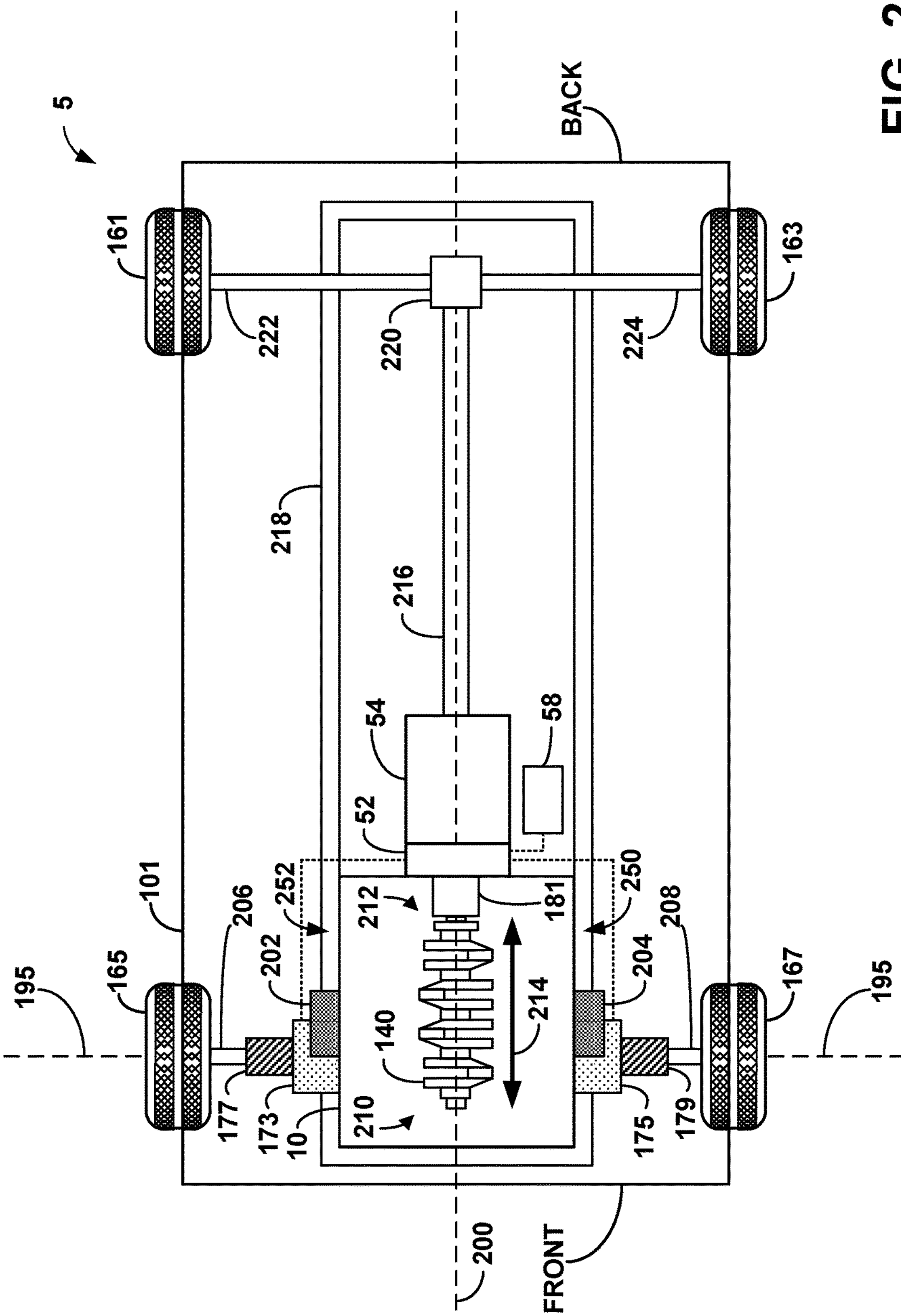

5
BACK
FRONT
161
163
165
167
195
195
200
101
218
216
220
222
224
54
58
52
181
212
214
210
140
250
252
202
204
206
208
10
173
175
177
179

FIG. 2

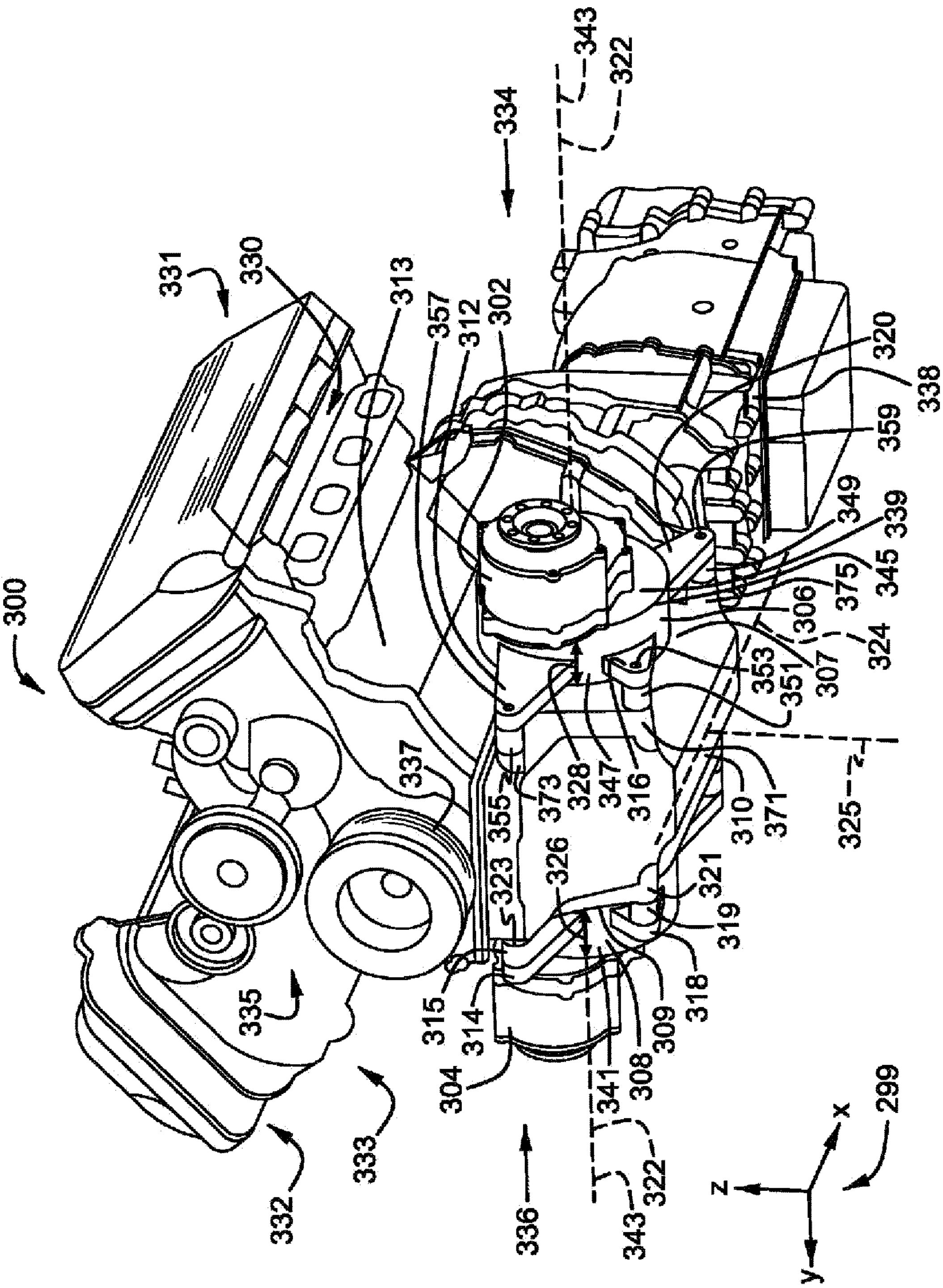

300
331
330
313
357
312
302
334
343
322
320
338
359
349
339
345
375
306
307
324
353
351
371
325
310
316
347
328
373
355
337
323
326
321
319
318
309
308
341
314
315
304
335
333
332
336
343
322
299
x
y
z

FIG. 3

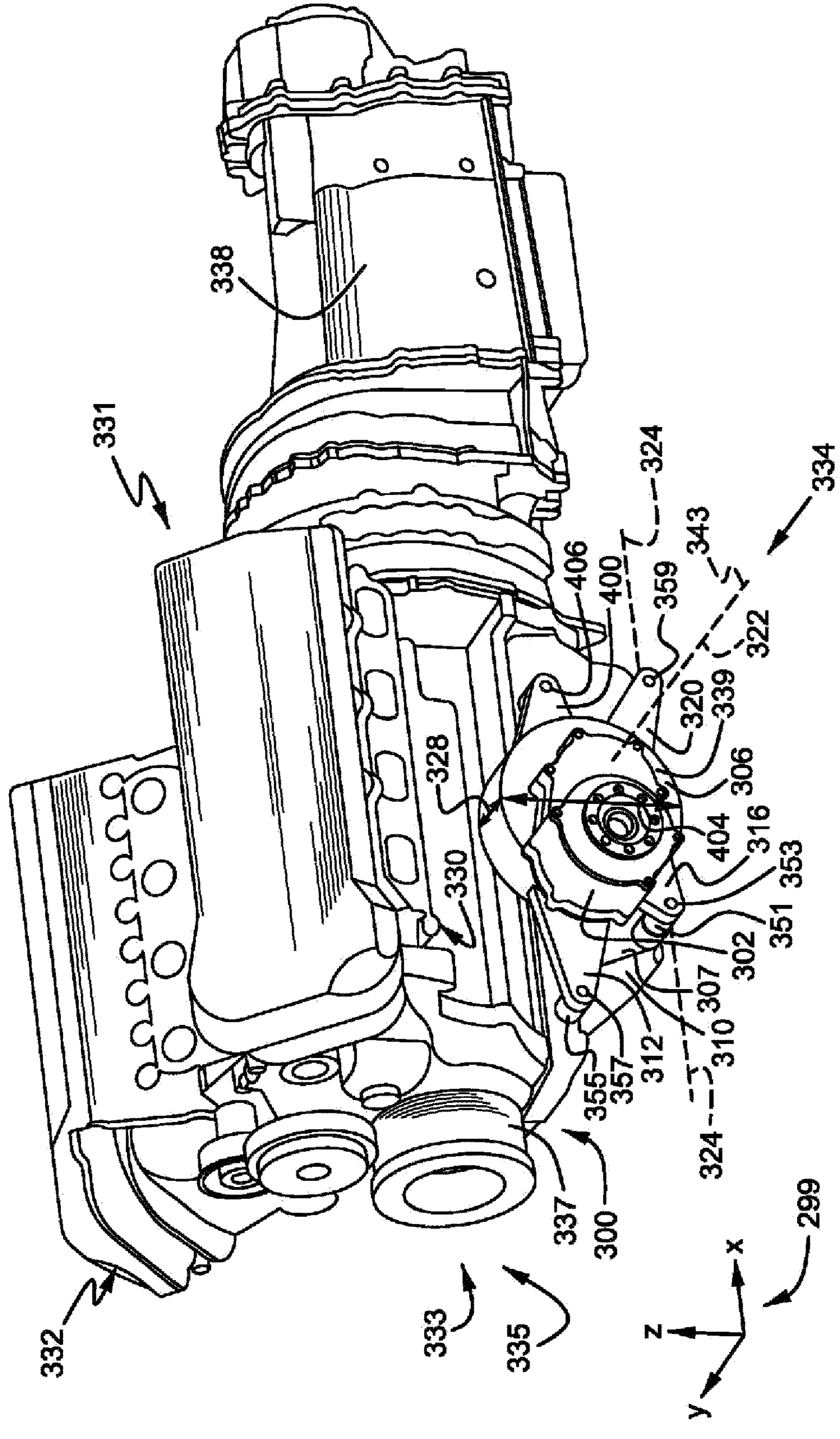

338
331
324
334
343
406
400
359
322
320
339
306
328
330
404
316
353
351
302
307
310
312
357
355
324
337
300
299
333
335
332
x
y
z

FIG. 4

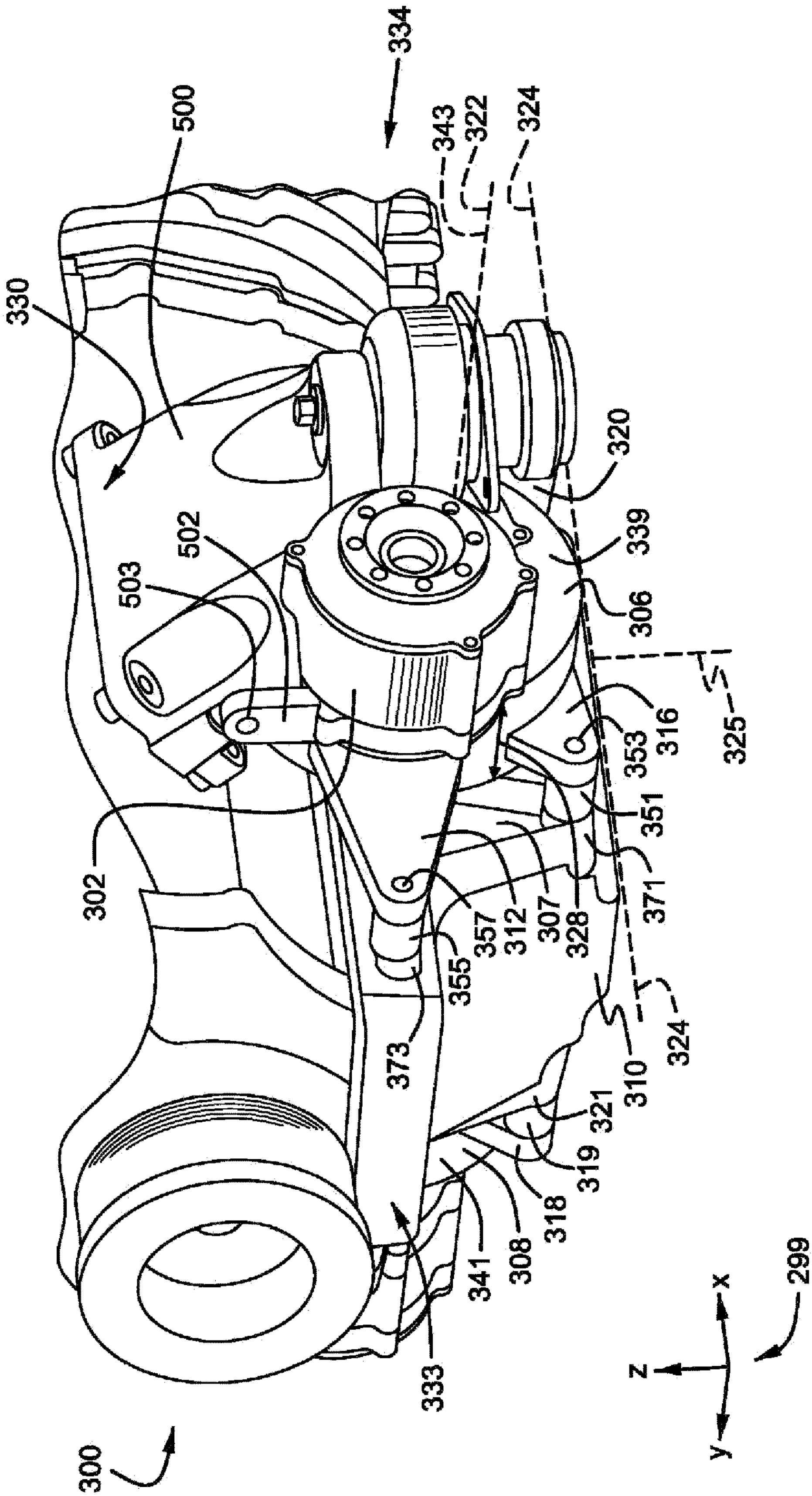

334
343
322
324
500
330
320
339
306
502
503
316
353
325
351
302
357
312
307
328
371
355
373
310
324
321
319
318
308
341
333
300
299
x
z
y

FIG. 5

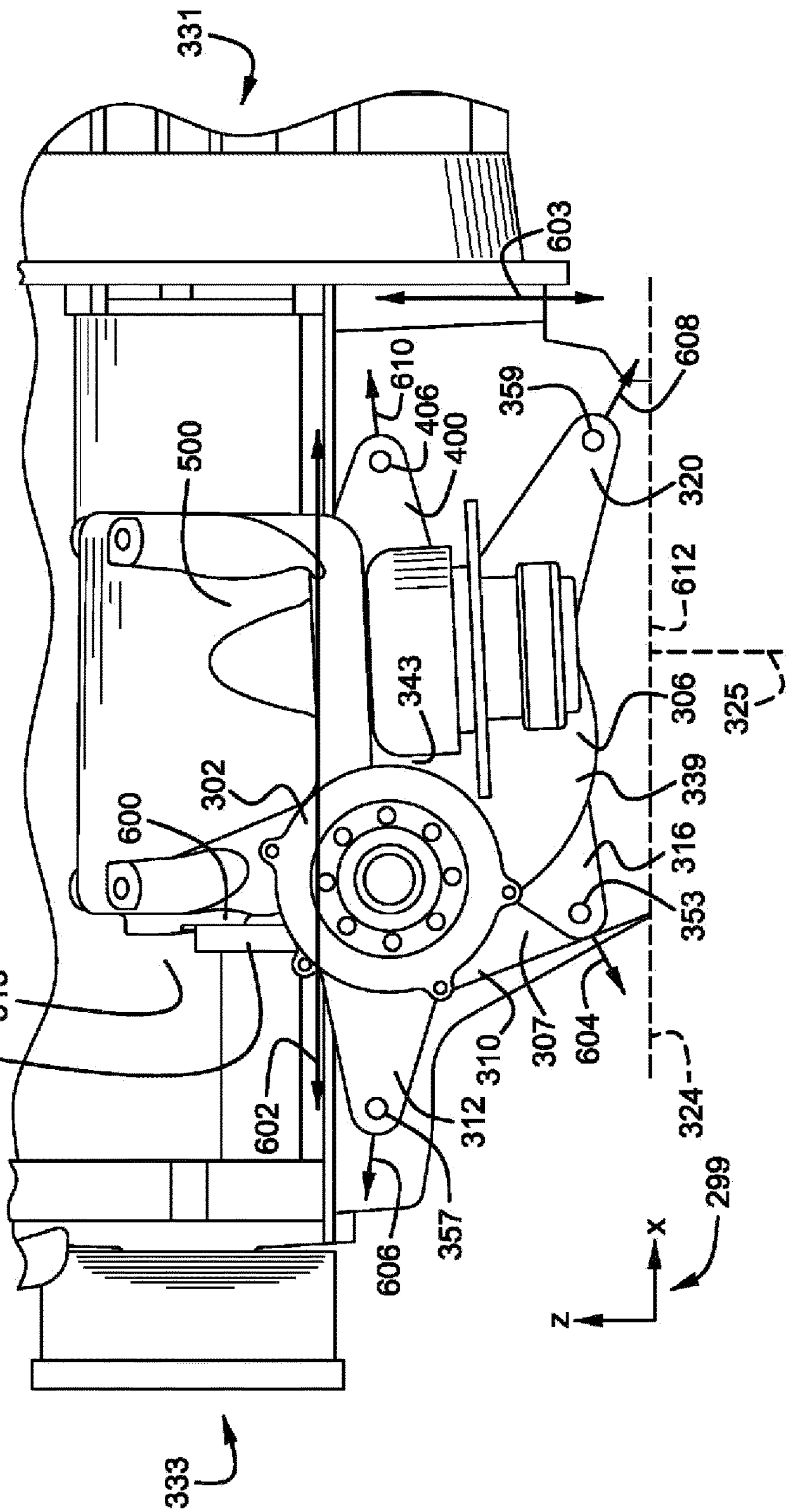

331
603
608
610
406
400
359
500
320
612
343
306
325
302
339
600
316
353
313
307
310
604
502
602
312
324
357
606
299
x
z
333

FIG. 6

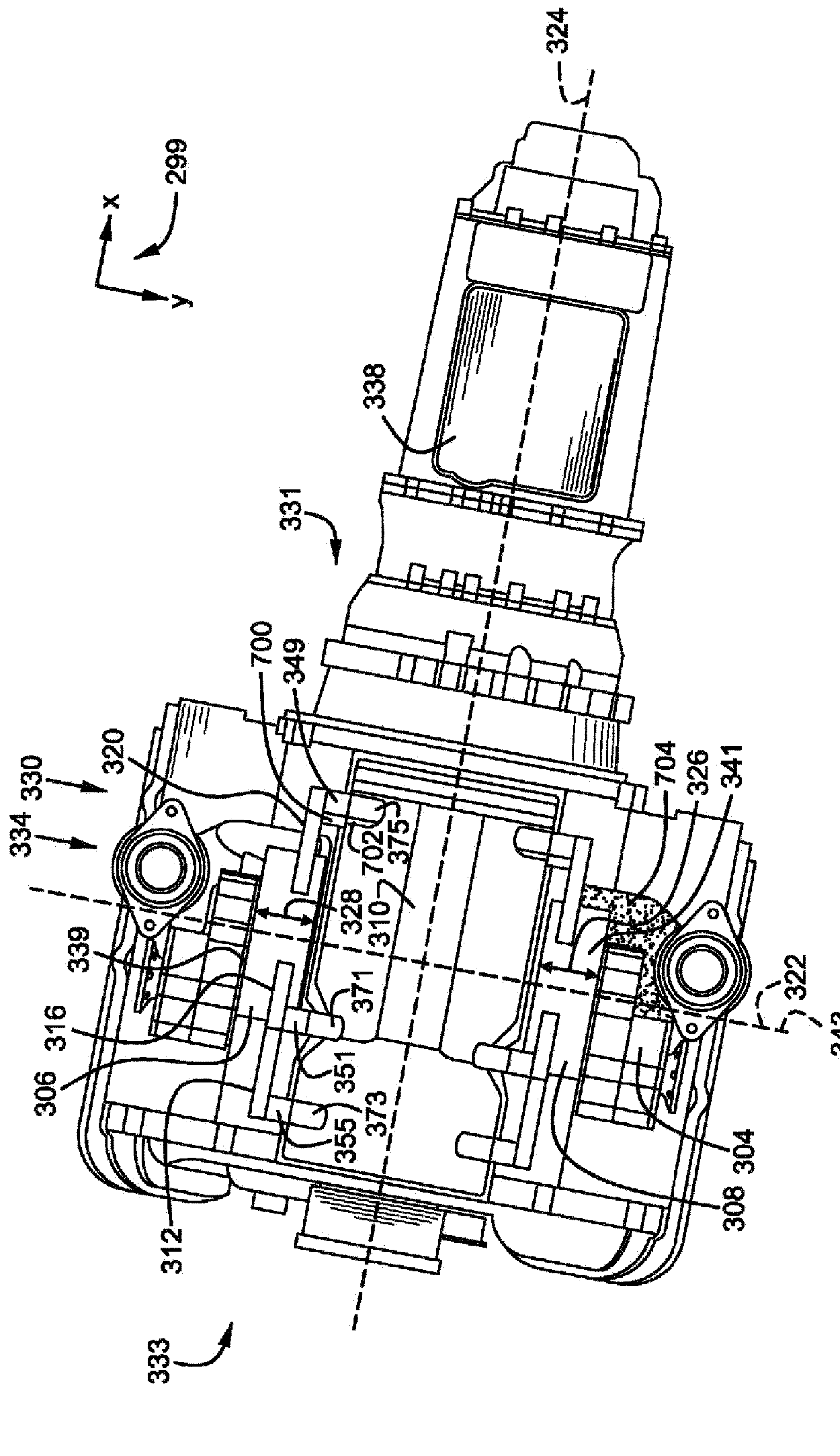

324
299
x
y
338
331
700
349
320
330
334
702
375
328
310
339
371
316
306
351
355
373
312
704
326
341
322
343
304
308
333

FIG. 7

TWIN MOTOR DRIVE SYSTEM FOR HYBRID ELECTRIC VEHICLE

FIELD

[0001] The present description relates generally to methods and systems for hybrid electric vehicles including a front-wheel drive system and a rear-wheel drive system.

BACKGROUND/SUMMARY

[0002] A motorized vehicle may include an all-wheel drive system configured to provide torque to wheels positioned at each end of the vehicle. The all-wheel drive system may increase wheel traction with a ground surface on which the vehicle sits to increase acceleration and decrease wheel slippage. In some examples, each wheel may be driven by an internal combustion engine of the vehicle. In order to drive each wheel, torque produced by the engine may be received by a transmission of the vehicle. An output of the transmission is coupled to a transfer case in order to provide the torque to one or more drive shafts coupled to the transfer case. However, in vehicles having a smaller amount of space for drivetrain components, packaging the components of an all-wheel drive system may be difficult. As a result, some vehicles may include wheels driven by a different type of motor, such as an electric motor.

[0003] One example approach of an all-wheel drive system is shown by Plishner in U.S. Pat. No. 6,880,654. Therein, a motorized vehicle is disclosed having a distributed motor system with a plurality of electric drive motors each coupled to a respective traction wheel. Each electric drive motor, steering motor, and wheel positioning motor may be integrated into a wheel manipulator element, and the wheel manipulator element may provide signals indicating the motion of the wheels to a controller of the vehicle.

[0004] Another example approach is shown by Thomas et al. in U.S. Pat. No. 7,384,357. Therein, a hybrid powertrain for a four-wheel drive vehicle is disclosed. The vehicle includes a front wheel drive system having front half shafts driveably connected to front wheels and driven by an electric motor drive unit. The powertrain also includes a rear wheel drive system having rear axle shafts driveably connected to rear wheels, the rear axle shafts driven by an internal combustion engine through a transmission, a drive shaft, and an inter-wheel differential mechanism.

[0005] However, the inventors herein have recognized potential issues with such systems. As one example, an electric motor configured to drive both front wheels of a vehicle, together, as described by the '357 patent may occupy a relatively larger amount of space. The electric motor in this configuration may not be suitable for vehicles having an internal combustion engine mounted in a longitudinal arrangement within the vehicle, such as a V-engine with cylinder banks positioned opposite to each other across a longitudinal axis of the vehicle. Such engine arrangements may not include an amount of space within the engine compartment to house the electric motor. As another example, a distributed motor system with different electric motors coupled to each wheel of a vehicle, such as that described by the '654 patent, may consume larger amounts of electrical energy in order to power the drivetrain of the vehicle. The larger amounts of electrical energy consumed may require electrical components (e.g., batteries, generators, etc.) with an increased size, complexity, and/or cost, and the electrical components may be difficult to maintain and/or repair.

[0006] In one example, the issues described above may be addressed by a system, comprising: a longitudinally mounted engine adapted to drive rear wheels of a vehicle; and two, independent, electric motors mounted to the engine, on opposite sides of the engine, and adapted to drive front wheels of the vehicle, where the two electric motors are not rotationally coupled to the engine. In this way, the engine may provide torque to the rear wheels of the engine, and the front wheels may be driven independently from the rear wheels by the two electric motors.

[0007] As one example, each of the two electric motors may be a pancake motor, with a diameter of each electric motor being greater than a width of each electric motor. The electric motors may be mounted directly to an oil pan of the engine and opposite to each other relative to a longitudinal axis of the engine. Each electric motor may be directly coupled to different reduction gearboxes in order to provide a torque output of each electric motor to front wheel axles of the vehicle. The engine may further include an integrated starter motor/generator configured to supply electrical power to the electric motors, with the starter motor/generator receiving torque from a crankshaft of the engine. By coupling the electric motors directly to the oil pan of the engine, an amount of space occupied by the electric motors within the vehicle may be reduced, and the electric motors may be selectively energized in order to drive the front wheels independently of the rear wheels. Additionally, by supplying electrical power to the electric motors via the integrated starter/generator, an electrical load on one or more batteries of the vehicle may be reduced during conditions such as engine idling.

[0008] It should be understood that the summary above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** shows a schematic diagram of an engine system including front wheels driven by electric motors.

[0010] FIG. **2** shows a schematic diagram of a vehicle including the engine system of FIG. **1**.

[0011] FIG. **3** shows a perspective view of an engine system including a first electric motor coupled to a first side of an engine and a second electric motor coupled to a second side of the engine.

[0012] FIG. **4** shows a second perspective view of the engine system shown by FIG. **3**.

[0013] FIG. **5** shows a third perspective view of the engine system shown by FIGS. **3-4** and shows the first electric motor coupled to a first engine mount.

[0014] FIG. **6** shows a side view of the engine system shown by FIGS. **3-5** with the first electric motor coupled to the first engine mount.

[0015] FIG. **7** shows a bottom view of the engine system shown by FIGS. **3-6**.

[0016] FIGS. **3-7** are shown to scale, though other relative dimensions may be used.

DETAILED DESCRIPTION

[0017] The following description relates to systems and methods for an all-wheel drive system of a hybrid electric vehicle. A hybrid electric vehicle, such as the hybrid electric vehicle shown by FIGS. **1-2**, includes a front-wheel drive system and a rear-wheel drive system. The rear-wheel drive system includes an internal combustion engine mounted along a longitudinal axis of the vehicle and positioned at a front end of the vehicle. The engine is configured to supply torque to rear wheels of the vehicle via a drive shaft. The front-wheel drive system includes a first electric motor directly coupled to a first side of the engine and a second electric motor directly coupled to a second side of the engine, as shown by FIG. **3**. Each electric motor may be a pancake motor including a cylindrical section, with a diameter of the cylindrical section being less than a length of the cylindrical section, as shown by FIG. **4**. The length of the cylindrical section is positioned parallel to a mounting axis of each electric motor, and the mounting axis of each electric motor is positioned perpendicular to the longitudinal axis of the vehicle, as shown by FIG. **7**. Each electric motor includes a reduction gearbox coupled to a different front wheel axle of the vehicle, with the first electric motor driving a first front wheel axle via a first reduction gearbox, and with the second electric motor driving a second front wheel axle via a second reduction gearbox. A housing of each electric motor may be coupled to an oil pan of the engine by a plurality of arms, with each arm extending from the cylindrical section, as shown by FIG. **6**. The first electric motor may be additionally coupled to a first engine mount at the first side of the engine (as shown by FIG. **5**), and the second electric motor may be additionally coupled to a second engine mount at the second side of the engine. By coupling the first electric motor directly to the first side of the engine and the second electric motor directly to the second side of the engine, an amount of space occupied by the front-wheel drive system may be decreased, and the electric motors may be driven independently in order to rotate the front wheels of the vehicle independently relative to the rear wheels (and to each other).

[0018] FIG. **1** and FIG. **2** each schematically show various components included by a hybrid electric vehicle **5**. For example, FIG. **1** depicts an example of a cylinder **14** (which may be referred to herein as a combustion chamber) of internal combustion engine **10** included within vehicle **5**, and FIG. **2** schematically depicts the vehicle **5** from a top view in order to further illustrate components of the vehicle **5** (e.g., components of a front-wheel drive system **183** and a rear-wheel drive system **185** described below with reference to FIG. **1**). Some components shown by FIG. **1** may not be shown by FIG. **2** (or vice versa) for illustrative purposes.

[0019] Turning firstly to FIG. **1**, cylinder **14** of engine **10** is shown to include cylinder walls **136** capped by cylinder head **159**. The cylinder **14** includes a piston **138** positioned therein. Piston **138** is coupled to crankshaft **140** so that reciprocating motion of the piston is translated into rotational motion of the crankshaft. Engine **10** may be controlled at least partially by a control system including controller **12** and by input from a vehicle operator **130** via an input device **132**. In this example, input device **132** includes an accelerator pedal and a pedal position sensor **134** for generating a proportional pedal position signal PP.

[0020] Engine **10** is configured to provide torque to the rear-wheel drive system **185** of the vehicle **5** via crankshaft **140**. Specifically, crankshaft **140** is coupled to transmission **54** and provides input torque to transmission **54**, with the transmission **54** being a gearbox, a planetary gear system, or another type of transmission. The transmission **54** converts the input torque into an output torque via a plurality of gears internal to the transmission **54**, and the output torque is provided to the rear wheels of the vehicle by the transmission **54** in order to drive the rear wheels.

[0021] In some examples, the rear-wheel drive system **185** of the vehicle **5** may additionally include electric machine **52** configured to provide torque to first rear wheel **163** and second rear wheel **161** via transmission **54**. For example, electric machine **52** may be connected (e.g., coupled) to transmission **54** in order to drive transmission **54** and provide torque to first rear wheel **163** and second rear wheel **161** during conditions in which one or more clutches are engaged. In the depicted example, a first clutch **56** is provided between crankshaft **140** and electric machine **52**, and a second clutch **57** is provided between electric machine **52** and transmission **54**. Controller **12** may send a signal to an actuator of each clutch (e.g., first clutch **56** and/or second clutch **57**) to engage or disengage the clutches, so as to connect or disconnect crankshaft **140** from electric machine **52** and the components connected thereto, and/or connect or disconnect electric machine **52** from transmission **54** and the components connected thereto. Electric machine **52** receives electrical power from a traction battery **58** to provide torque to first rear wheel **163** and the second rear wheel **161**. Electric machine **52** may also be operated as a generator to provide electrical power to charge battery **58**, for example during a braking operation.

[0022] The rear-wheel drive system **185** may be configured to operate in various manners including a parallel configuration (e.g., with torque provided to the rear wheels by both engine **10** and electric machine **52**), a series configuration (e.g., with torque provided to the rear wheels by one of the engine **10** or the electric machine **52**, and with the other of engine **10** or electric machine **52** providing electrical energy to the vehicle **5**), or a series-parallel configuration. In other examples, the vehicle **5** may not include the electric machine **52**, with the rear wheels being driven by the crankshaft **140** of engine **10** as described above.

[0023] The front wheels of the vehicle **5** (e.g., first front wheel **167** and second front wheel **165**) are not driven by engine **10**. Instead, each front wheel is driven by a respective electric motor, with the driving of the front wheels being independent relative to the driving of the rear wheels (e.g., by rear-wheel drive system **185** as described above). Specifically, the front-wheel drive system **183** includes a first electric motor **175** coupled to the first front wheel **167** via a first reduction gearbox **179**, and the front-wheel drive system **183** additionally includes a second electric motor **173** coupled to the second front wheel **165** via a second reduction gearbox **177**. By driving the front wheels independently relative to the rear wheels, a traction of the front wheels (e.g., a frictional force between front wheels of the vehicle **5** and a ground surface on which the vehicle **5** sits) may be increased in order to more easily drive the vehicle **5**. For example, during conditions in which the rear wheels are unable to provide sufficient traction to drive the vehicle **5**

(e.g., conditions in which the rear wheels are positioned on surfaces of loosely packed particles, such as sand, or surfaces having a lower coefficient of friction, such as ice and/or snow), one or both of the front wheels may be driven independently of the rear wheels in order to move the vehicle **5**. In some examples, both of first electric motor **175** and second electric motor **173** may be energized in order to drive both of the front wheels (e.g., first front wheel **167** and second front wheel **165**, respectively). In other examples, only one of the electric motors may be energized to drive only a single front wheel independent of the other front wheel (e.g., first electric motor **175** may be energized in order to drive first front wheel **167** independently relative to second front wheel **165**, or second electric motor **173** may be energized to drive second front wheel **165** independently relative to first front wheel **167**). In some examples, a selected drive mode of the vehicle **5** (e.g., all-wheel drive, rear-wheel drive, dual front-wheel drive, single front-wheel drive, etc.) may be selected by the operator **130** of the vehicle **5** via one or more user interface devices (e.g., touchscreens, buttons, etc.) positioned within a cabin of the vehicle **5** and in electrical communication with controller **12**. In other examples, the drive mode of the vehicle **5** may be selected by the controller **12** responsive to detected and/or estimated operating conditions of the vehicle **5** (e.g., vehicle speed, engine speed, etc.). In yet other examples, the drive mode of the vehicle **5** may be selected by the controller **12** responsive to detected and/or estimated environmental conditions (e.g., detection of rain, snow, etc. by sensors of the vehicle **5**).

[0024] The crankshaft **140** may be coupled to an integrated starter/generator **181** to enable a starting operation of engine **10** and to provide electrical energy to battery **58**. For example, during conditions in which the engine **10** is in a non-operating mode (e.g., a mode in which the engine **10** is off and is not combusting fuel/air within engine cylinders, such as cylinder **14**), an operator of the vehicle **5** (e.g., a user, driver, etc.) may adjust the engine **10** from the non-operating mode to an operating mode (e.g., a mode in which the engine is on and is combusting fuel/air within engine cylinders, such as cylinder **14**) via user input to one or more user input devices of the vehicle (e.g., user interaction with input devices of ignition system **190**, such as pressing an ignition button within a cabin of the vehicle). The controller **12** may transmit an electrical signal to the starter/generator **181** in response to the user input in order to actuate the starter/generator **181** to rotate the crankshaft of the engine **10** to perform the starting operation (e.g., adjusting the engine from the non-operating mode to the operating mode). The controller **12** may also transmit electrical signals to spark plug **192** in order to produce spark within cylinder **14**, and/or the controller **12** may transmit electrical signals to adjust an amount of opening of a nozzle of fuel injector **166** and/or fuel injector **170** in order to provide fuel to cylinder **14**.

[0025] During conditions in which the engine is in the operating mode (e.g., the engine **10** is on and combusting fuel/air), the integrated starter/generator **181** may receive a portion of the torque produced by the crankshaft **140** in order to generate electrical energy to be stored by battery **58** and/or utilized to energize the electric motors (e.g., first electric motor **175** and/or second electric motor **173**) to drive the front wheels of the vehicle. For example, during conditions in which the engine **10** is operating at a lower engine speed (e.g., idling, coasting, etc.), the starter/generator **181** may generator electrical energy to be stored by battery **58**. During conditions in which the engine **10** is operating at a higher engine speed (e.g., during acceleration of the vehicle **5**), the starter/generator **181** may generate electric energy from the rotational motion of the crankshaft **140** and may route (e.g., provide, deliver, etc.) the electrical energy to the first electric motor **175** and/or second electric motor **173** in order to drive the first front wheel **167** and/or second front wheel **165**. In some examples, the first electric motor **175** and second electric motor **173** may be energized (e.g., by starter/generator **181** and/or battery **58**) in order to drive the front wheels during conditions in which the engine **10** is in the non-operating mode and/or during conditions in which the engine **10** is operating at a lower engine speed (e.g., idling).

[0026] Cylinder **14** can receive intake air via a series of intake air passages **142**, **144**, and **146**. Intake air passage **146** can communicate with other cylinders of engine **10** in addition to cylinder **14**. In some examples, one or more of the intake passages may be coupled to a boosting device such as a turbocharger or a supercharger. For example, FIG. **1** shows engine **10** configured with a turbocharger including a compressor **174** arranged between intake air passages **142** and **144**, and an exhaust turbine **176** arranged along exhaust passage **148**. Compressor **174** may be at least partially powered by exhaust turbine **176** via a shaft **180** where the boosting device is configured as a turbocharger. However, in other examples, such as where engine **10** is provided with a supercharger, exhaust turbine **176** may be optionally omitted, where compressor **174** may be powered by mechanical input from a motor or the engine **10**. A throttle **162** including a throttle plate **164** may be provided along an intake passage of the engine for varying the flow rate and/or pressure of intake air provided to the engine cylinders. For example, throttle **162** may be positioned downstream of compressor **174** as shown in FIG. **1**, or alternatively may be provided upstream of compressor **174**.

[0027] Exhaust passage **148** can receive exhaust gases from other cylinders of engine **10** in addition to cylinder **14**. Exhaust gas sensor **128** is shown coupled to exhaust passage **148** upstream of emission control device **178**. Sensor **128** may be selected from among various suitable sensors for providing an indication of exhaust gas air/fuel ratio such as a linear oxygen sensor or UEGO (universal or wide-range exhaust gas oxygen), a two-state oxygen sensor or EGO (as depicted), a HEGO (heated EGO), a NOx, HC, or CO sensor, for example. Emission control device **178** may be a three way catalyst (TWC), NOx trap, various other emission control devices, or combinations thereof.

[0028] Each cylinder of engine **10** includes one or more intake valves and one or more exhaust valves. For example, cylinder **14** is shown including at least one intake poppet valve **150** and at least one exhaust poppet valve **156** located at an upper region of cylinder **14** (e.g., disposed within cylinder head **159**). In some examples, each cylinder of engine **10**, including cylinder **14**, may include at least two intake poppet valves and at least two exhaust poppet valves located at an upper region of the cylinder.

[0029] Intake valve **150** may be controlled by controller **12** via actuator **152**. Similarly, exhaust valve **156** may be controlled by controller **12** via actuator **154**. During some conditions, controller **12** may vary the signals provided to actuators **152** and **154** to control the opening and closing of the respective intake and exhaust valves. The position of intake valve **150** and exhaust valve **156** may be determined by respective valve position sensors (not shown). The valve actuators may be of the electric valve actuation type or cam actuation type, or a combination thereof. The intake and exhaust valve timing may be controlled concurrently or any of a possibility of variable intake cam timing, variable exhaust cam timing, dual independent variable cam timing or fixed cam timing may be used. Each cam actuation system may include one or more cams and may utilize one or more of cam profile switching (CPS), variable cam timing (VCT), variable valve timing (VVT), and/or variable valve lift (VVL) systems that may be operated by controller **12** to vary valve operation. For example, cylinder **14** may alternatively include an intake valve controlled via electric valve actuation and an exhaust valve controlled via cam actuation including CPS and/or VCT. In other examples, the intake and exhaust valves may be controlled by a common valve actuator or actuation system, or a variable valve timing actuator or actuation system.

[0030] Cylinder **14** can have a compression ratio, which is the ratio of volumes when piston **138** is at bottom center to top center. In one example, the compression ratio is in the range of 9:1 to 10:1. However, in some examples where different fuels are used, the compression ratio may be increased. This may happen, for example, when higher octane fuels or fuels with higher latent enthalpy of vaporization are used. The compression ratio may also be increased if direct injection is used due to its effect on engine knock.

[0031] In some examples, each cylinder of engine **10** may include spark plug **192** for initiating combustion. Ignition system **190** can provide an ignition spark to cylinder **14** via spark plug **192** in response to spark advance signal SA from controller **12**, under select operating modes. However, in some embodiments, spark plug **192** may be omitted, such as where engine **10** may initiate combustion by auto-ignition or by injection of fuel as may be the case with some diesel engines.

[0032] In some examples, each cylinder of engine **10** may be configured with one or more fuel injectors for providing fuel thereto. As a non-limiting example, cylinder **14** is shown including two fuel injectors **166** and **170**. Fuel injectors **166** and **170** may be configured to deliver fuel received from fuel system **8**. Fuel system **8** may include one or more fuel tanks, fuel pumps, and/or fuel rails. Fuel injector **166** is shown coupled directly to cylinder **14** for injecting fuel directly therein in proportion to the pulse width of signal FPW-**1** received from controller **12** via electronic driver **168**. In this manner, fuel injector **166** provides what is known as direct injection (hereafter referred to as "DI") of fuel into combustion cylinder **14**. While FIG. **1** shows injector **166** positioned to one side of cylinder **14**, it may alternatively be located overhead of the piston, such as near the position of spark plug **192**. Such a position may increase mixing and combustion when operating the engine with an alcohol-based fuel due to the lower volatility of some alcohol-based fuels. Alternatively, the injector may be located overhead and near the intake valve to increase mixing. Fuel may be delivered to fuel injector **166** from a fuel tank of fuel system **8** via a high pressure fuel pump, and a fuel rail. Further, the fuel tank may have a pressure transducer providing a signal to controller **12**.

[0033] Fuel injector **170** is shown arranged in intake passage **146**, rather than in cylinder **14**, in a configuration that provides what is known as port injection of fuel (hereafter referred to as "PFI") into the intake port upstream of cylinder **14**. Fuel injector **170** may inject fuel, received from fuel system **8**, in proportion to the pulse width of signal FPW-**2** received from controller **12** via electronic driver **171**. Note that a single driver **168** or **171** may be used for both fuel injection systems, or multiple drivers, for example driver **168** for fuel injector **166** and driver **171** for fuel injector **170**, may be used, as depicted.

[0034] In an alternate example, each of fuel injectors **166** and **170** may be configured as direct fuel injectors for injecting fuel directly into cylinder **14**. In still another example, each of fuel injectors **166** and **170** may be configured as port fuel injectors for injecting fuel upstream of intake valve **150**. In yet other examples, cylinder **14** may include only a single fuel injector that is configured to receive different fuels from the fuel systems in varying relative amounts as a fuel mixture, and is further configured to inject this fuel mixture either directly into the cylinder as a direct fuel injector or upstream of the intake valves as a port fuel injector. As such, it should be appreciated that the fuel systems described herein should not be limited by the particular fuel injector configurations described herein by way of example.

[0035] Fuel may be delivered by both injectors to the cylinder during a single cycle (e.g., combustion cycle) of the cylinder. For example, each injector may deliver a portion of a total fuel injection that is combusted in cylinder **14**. Further, the distribution and/or relative amount of fuel delivered from each injector may vary with operating conditions, such as engine load, knock, and exhaust temperature, such as described herein below. The port injected fuel may be delivered during an open intake valve event, closed intake valve event (e.g., substantially before the intake stroke), as well as during both open and closed intake valve operation. Similarly, directly injected fuel may be delivered during an intake stroke, as well as partly during a previous exhaust stroke, during the intake stroke, and partly during the compression stroke, for example. As such, even for a single combustion event, injected fuel may be injected at different timings from the port and direct injector. Furthermore, for a single combustion event, multiple injections of the delivered fuel may be performed per cycle. The multiple injections may be performed during the compression stroke, intake stroke, or any appropriate combination thereof.

[0036] Fuel injectors **166** and **170** may have different characteristics. These include differences in size, for example, one injector may have a larger injection hole than the other. Other differences include, but are not limited to, different spray angles, different operating temperatures, different targeting, different injection timing, different spray characteristics, different locations etc. Moreover, depending on the distribution ratio of injected fuel among injectors **170** and **166**, different effects may be achieved.

[0037] Fuel tanks in fuel system **8** may hold fuels of different fuel types, such as fuels with different fuel qualities and different fuel compositions. The differences may include different alcohol content, different water content, different octane, different heats of vaporization, different fuel blends, and/or combinations thereof etc. One example of fuels with different heats of vaporization could include gasoline as a first fuel type with a lower heat of vaporization and ethanol as a second fuel type with a greater heat of vaporization. In another example, the engine may use gasoline as a first fuel type and an alcohol containing fuel blend such as E85 (which is approximately 85% ethanol and 15% gasoline) or M85 (which is approximately 85% methanol and 15% gasoline) as a second fuel type. Other feasible substances include water, methanol, a mixture of alcohol and water, a mixture of water and methanol, a mixture of alcohols, etc.

[0038] In still another example, both fuels may be alcohol blends with varying alcohol composition wherein the first fuel type may be a gasoline alcohol blend with a lower concentration of alcohol, such as E10 (which is approximately 10% ethanol), while the second fuel type may be a gasoline alcohol blend with a greater concentration of alcohol, such as E85 (which is approximately 85% ethanol). Additionally, the first and second fuels may also differ in other fuel qualities such as a difference in temperature, viscosity, octane number, etc. Moreover, fuel characteristics of one or both fuel tanks may vary frequently, for example, due to day to day variations in tank refilling.

[0039] Controller **12** is shown in FIG. **1** as a microcomputer, including microprocessor unit **106**, input/output ports **108**, an electronic storage medium for executable programs and calibration values shown as non-transitory read only memory chip **110** in this particular example for storing executable instructions, random access memory **112**, keep alive memory **114**, and a data bus. Controller **12** may receive various signals from sensors coupled to engine **10**, in addition to those signals previously discussed, including measurement of inducted mass air flow (MAF) from mass air flow sensor **122**; engine coolant temperature (ECT) from temperature sensor **116** coupled to cooling sleeve **118**; a profile ignition pickup signal (PIP) from Hall effect sensor **120** (or other type) coupled to crankshaft **140**; throttle position (TP) from a throttle position sensor; and absolute manifold pressure signal (MAP) from sensor **124**. Engine speed signal, RPM, may be generated by controller **12** from signal PIP. Manifold pressure signal MAP from a manifold pressure sensor may be used to provide an indication of vacuum, or pressure, in the intake manifold. Controller **12** may infer an engine temperature based on an engine coolant temperature.

[0040] The controller **12** receives signals from the various sensors of FIG. **1** and employs the various actuators of FIG. **1** to adjust engine operation based on the received signals and instructions stored on a memory of the controller. For example, adjusting an output of the first electric motor **175** may include adjusting an amplitude and/or frequency of an electrical signal transmitted to the first electric motor **175** by the controller **12**. In one example, the controller **12** may adjust the output of the first electric motor **175** by adjusting a voltage supplied to the first electric motor **175** via the battery **58** and/or the starter/generator **181**. In another example, the controller **12** may adjust a rotational speed of the first front wheel **167** by transmitting electrical signals to the first reduction gearbox **179** in order to adjust a selected gear ratio of the first reduction gearbox **179**.

[0041] As described above, FIG. **1** shows only one cylinder of a multi-cylinder engine. As such, each cylinder may similarly include its own set of intake/exhaust valves, hydraulic lash adjusters, rocker arms, fuel injector(s), spark plug, etc. It will be appreciated that engine **10** may include any suitable number of cylinders, including 2, 3, 4, 5, 6, 8, 10, 12, or more cylinders. Further, each of these cylinders can include some or all of the various components described and depicted by FIG. **1** with reference to cylinder **14**.

[0042] FIG. **2** shows a body **101** of vehicle **5** with a front end, labeled "FRONT", and a back end labeled "BACK." Vehicle **5** includes the first front wheel **167** and the second front wheel **165** positioned at the front end of the vehicle, and also includes the first rear wheel **163** and the second rear wheel **161** positioned at the back end of the vehicle. As described above with reference to FIG. **1**, vehicle **5** includes internal combustion engine **10** configured to drive the first rear wheel **163** and the second rear wheel **161** via transmission **54**.

[0043] The engine **10** is mounted longitudinally within the vehicle **5** such that the crankshaft **140** of the engine is positioned parallel to a longitudinal axis **200** of the vehicle **5** (e.g., an axis extending from the front end to the back end of the vehicle). The engine **10** may be mounted (e.g., coupled) to a frame **218** of the vehicle **5** via one or more engine mounts. For example, FIG. **2** shows a first engine mount **204** and second engine mount **202** coupling the engine **10** to the frame **218** at opposite sides of the engine **10** (e.g., opposite relative to the longitudinal axis **200**). In this configuration, a length **214** of the crankshaft **140** is positioned parallel to the longitudinal axis **200**. A first end **210** of the crankshaft **140** may provide torque to one or more auxiliary components of the vehicle (e.g., fans, a cabin air condition system, fluid pumps, etc.). A second end **212** is coupled to the transmission **54** and provides torque for driving the first rear wheel **163** and the second rear wheel **161** (e.g., via drive shaft **216** coupled to first rear axle **224** and second rear axle **222** via differential **220**).

[0044] The first electric motor **175** is mounted (e.g., coupled) to a first side **250** of the engine **10** and the second electric motor **173** is mounted to a second side **252** of the engine **10**. In some examples (as described below with reference to FIGS. **3-7**), the first electric motor **175** and second electric motor **173** may each be directly coupled to an oil pan of the engine **10**. The oil pan may be coupled to an engine block of the engine **10** to seal an opening at a bottom of a crankcase of the engine **10**, with the crankcase housing the crankshaft **140**. The first electric motor **175** and second electric motor **173** are not rotationally coupled to the engine **10**. For example, rotating the crankshaft **140** of the engine **10** does not rotate the first electric motor **175** or the second electric motor **173** relative to the engine **10**.

[0045] The first electric motor **175** is shown coupled to first reduction gearbox **179**, and the second electric motor **173** is shown coupled to the second reduction gearbox **177**. The first reduction gearbox **179** is positioned between an output end of the first electric motor **175** and a first front axle **208**, and the second reduction gearbox **177** is positioned between an output end of the second electric motor **173** and a second front axle **206**. The first front axle **208** is coupled to first front wheel **167** and the second front axle **206** is coupled to the second front wheel **165**. Rotating the first front axle **208** may drive (e.g., rotate) the first front wheel **167**, and rotating the second front axle **206** may drive the second front wheel **165**. In one example, the first front axle **208** is driven by an output of the first reduction gearbox **179**, and the output of the first reduction gearbox **179** is driven by an input of the first reduction gearbox **179** coupled to an output of the first electric motor **175**. The first reduction gearbox **179** may include a plurality of gears configured to adjust a gear ratio of the input of the first reduction gearbox **179** to the output of the first reduction gearbox **179**. The controller **12** (shown by FIG. **1**) may transmit electrical signals to the first reduction gearbox **179** in order to adjust the gear ratio in response to vehicle operating conditions (e.g., in response to a detected engine load, vehicle speed, etc.). Although the coupling of the first electric motor **175** to first reduction gearbox **179** and first front axle **208** are described herein as an example, the second electric motor **173**, second reduction gearbox **177**, and second front axle **206** are coupled (and operate) in a similar way.

[0046] The first front axle **208** and second front axle **206** are each positioned along a latitudinal axis **195** of the vehicle **5**. The latitudinal axis **195** is positioned perpendicular to the longitudinal axis **200** and is a rotational axis of the first front axle **208** and the second front axle **206**. Said another way, the first electric motor **175** drives the first front axle **208** to rotate about latitudinal axis **195**, and the second electric motor **173** drives the second front axle **206** to rotate about latitudinal axis **195**. In some examples, an output end of the first electric motor **175** and/or an output end of the second electric motor **173** may additionally be positioned along the latitudinal axis **195**.

[0047] As described above with reference to FIG. **1**, the vehicle **5** may include integrated starter/generator **181** coupled to crankshaft **140**. The starter/generator **181** may provide operating voltages to the first electric motor **175** and second electric motor **173** during operation of the engine **10**.

[0048] During some engine operating conditions (e.g., engine idling, coasting, etc.), engine **10** may be operated to drive starter/generator **181** which may in turn provide a generator function to convert the engine output to electrical energy, where the electrical energy may be stored in battery **58** for later use by the motor. Embodiments of battery **58** may include one or more rechargeable batteries, fuel cells, and/or capacitors for example. In these examples, electrical energy may be temporarily converted to chemical or potential energy for storage.

[0049] In some embodiments, battery **58** may be configured to store electrical energy that may be supplied to other electrical loads residing on-board the vehicle (other than the first electric motor **175** and second electric motor **173**), including cabin heating and air conditioning, engine starting, headlights, cabin audio and video systems, etc.

[0050] Controller **12** may communicate with one or more of engine **10**, starter/generator **181**, first electric motor **175**, second electric motor **173**, first reduction gearbox **179**, second reduction gearbox **177**, and battery **58**. Controller **12** may receive sensory feedback information from one or more of engine **10**, starter/generator **181**, first electric motor **175**, second electric motor **173**, first reduction gearbox **179**, second reduction gearbox **177**, and battery **58**. Further, controller **12** may send control signals to one or more of engine **10**, starter/generator **181**, first electric motor **175**, second electric motor **173**, first reduction gearbox **179**, second reduction gearbox **177**, and battery **58** responsive to this sensory feedback. Controller **12** may receive an indication of an operator requested output of the vehicle propulsion system from vehicle operator **130** (shown by FIG. **1**). For example, controller **12** may receive sensory feedback from pedal position sensor **134** which communicates with pedal **132**. Pedal **132** may refer schematically to a brake pedal and/or an accelerator pedal.

[0051] In some embodiments, battery **58** may periodically receive electrical energy from a power source residing external to the vehicle (e.g. not part of the vehicle). As a non-limiting example, the propulsion system of vehicle **5** may be configured as a plug-in hybrid electric vehicle (HEV), whereby electrical energy may be supplied to battery **58** from the external power source via an electrical energy transmission cable. During a recharging operation of battery **58** from the external power source, the electrical transmission cable may electrically couple the battery **58** and the external power source. While the vehicle propulsion system is operated to propel the vehicle, the electrical transmission cable may disconnected between the external power source and the battery **58**. Controller **12** may identify and/or control the amount of electrical energy stored at the energy storage device, which may be referred to as the state of charge (SOC).

[0052] In other embodiments, the electrical transmission cable may be omitted, where electrical energy may be received wirelessly at battery **58** from the external power source. For example, battery **58** may receive electrical energy from the external power source via one or more of electromagnetic induction, radio waves, and electromagnetic resonance. As such, it should be appreciated that any suitable approach may be used for recharging battery **58** from a power source that does not comprise part of the vehicle.

[0053] FIGS. **3-7** show an engine **300** similar to the engine **10** described above with reference to FIGS. **1-2**. The engine **300** is mounted longitudinally within a vehicle (not shown) similar to the vehicle **5** described above. A first electric motor **306** is directly coupled to a first side **334** of the engine **300**, and a second electric motor **308** is directly coupled to a second side **336** of the engine **300** (similar to first electric motor **175** and second electric motor **173**, respectively, described above with reference to FIGS. **1-2**). FIGS. **3-7** each show different perspective views of the engine **300** in order to illustrate the arrangement of the first electric motor **306** and the second electric motor **308** relative to other components of the vehicle. Reference axes **299** are included by each of FIGS. **3-7** for comparison of the views shown.

[0054] In the example shown by FIGS. **3-7**, engine **300** is a V-engine with a first plurality of cylinders (e.g., cylinders similar to cylinder **14** described above with reference to FIG. **1**) positioned in a first cylinder bank **330** and a second plurality of cylinders positioned in a second cylinder bank **332**. In alternate embodiments, the engine **300** may be different type of engine (e.g., an inline engine including a single cylinder bank with each cylinder positioned along a same axis) with a different number of cylinders, different relative arrangement of cylinders and/or cylinder banks, etc.

[0055] The first side **334** of the engine **300** is positioned opposite to the second side **336** relative to a longitudinal axis **324** of the engine **300**. The longitudinal axis **324** of the engine **300** is aligned with (e.g., positioned parallel to and in a same space as) a longitudinal axis of the vehicle (e.g., longitudinal axis **200** of vehicle **5** described above with reference to FIGS. **1-2**). In the example shown by FIGS. **3-7**, the first cylinder bank **330** is positioned at the first side **334** and the second cylinder bank **332** is positioned at the second side **336**.

[0056] The engine **300** includes an oil pan **310**, with the oil pan **310** positioned along the longitudinal axis **324** and coupled to an engine block **313** of the engine **300**. Specifically, oil pan **310** is coupled to the engine block **313** at a position vertically below the first cylinder bank **330** and the second cylinder bank **332** relative to a ground surface on which the vehicle sits. The oil pan **310** is centered between the first cylinder bank **330** and the second cylinder bank **332** and is positioned along a central vertical axis **325** of the engine **300**. A first exterior surface **307** of the oil pan **310** is positioned at the first side **334**, and a second exterior surface **309** of the oil pan **310** is positioned at the second side **336**.

[0057] The vehicle includes a transmission **338** coupled to the engine **300** along the longitudinal axis **324**. The transmission **338** is coupled to the engine block **313** at a rear end **331** of the engine **300**. The rear end **331** is positioned opposite to a front end **333** in a direction of the longitudinal axis **324**. The transmission **338** is provided torque by a crankshaft (similar to crankshaft **140** shown by FIGS. **1-2** and described above) of the engine in order to drive rear wheels of the vehicle (similar to first rear wheel **163** and second rear wheel **161** described above). The front end **333** of the engine **300** may include a front end accessory drive **335** (FEAD) having a plurality of pulleys (e.g., pulley **337**). One or more of the pulleys of the FEAD may be driven by the crankshaft in order to drive auxiliary components of the vehicle (e.g., fans, a cabin air condition system, fluid pumps, etc.).

[0058] The first electric motor **306** is directly coupled to the first exterior surface **307** of the oil pan **310** at the first side **334**, and the second electric motor **308** is directly coupled to the second exterior surface **309** of the oil pan **310** at the second side **336**. A mounting axis **322** of each electric motor is positioned perpendicular to the longitudinal axis **324** of the engine **300** (as shown by FIG. **7**) and parallel to a rotational axis of the front wheels of the vehicle (e.g., latitudinal axis **195** through first front wheel **167** and second front wheel **165** as described above with reference to FIGS. **1-2**). Each electric motor may include a cylindrical section (e.g., cylindrical section **339** of the first electric motor **306** and cylindrical section **341** of the second electric motor **308**), and each electric motor may be coupled to the oil pan **310** in a position in which a central axis of each cylindrical section is parallel to the mounting axis **322** and positioned along the mounting axis **322**.

[0059] In the example shown by FIGS. **3-7**, first electric motor **306** and second electric motor **308** each include a plurality of arms and axial extensions shaped to couple the electric motors to the respective surfaces of the oil pan **310** (e.g., to couple first electric motor **306** to first exterior surface **307**, and to couple second electric motor **308** to second exterior surface **309**). For example, a housing **345** of the first electric motor **306** includes a first arm **316**, a second arm **312**, a third arm **320**, and a fourth arm **400** (shown by FIG. **4** and FIG. **6**) each extending in an outward direction (e.g., away from the central axis **343** of the cylindrical section **339** and away from the mounting axis **322**) relative to a side surface **347** of the first electric motor **306**. The side surface **347** is positioned to surround the mounting axis **322** and the central axis **343** of the cylindrical section **339**, and the side surface **347** has a width **328** in a direction parallel to the central axis **343** of the cylindrical section **339**. In one example, each arm may be positioned radially relative to the central axis **343** of the cylindrical section **339**. In other examples (such as the example shown by FIGS. **3-7**), one or more of the arms may be angled by a different amount relative to the central axis **343** than each other arm.

[0060] As shown by FIG. **6**, each arm of the first electric motor **306** (e.g., first arm **316**, a second arm **312**, a third arm **320**, and fourth arm **400**) extends in a different direction relative to each other arm. For example, the first arm **316** extends in a first direction **604** away from the central axis **343**, toward the front end **333** of the engine **300**, and vertically toward a bottom surface **612** of the oil pan **310** (e.g., vertically relative to the ground surface on which the vehicle sits, in a direction of the z-axis shown by reference axes **299**). Second arm **312** extends in a second direction **606** away from the central axis **343**, toward the front end **333**, and away from the bottom surface **612** of the oil pan **310**, toward the engine block **313**. Third arm **320** extends in a third direction **608** away from the central axis **343**, toward the rear end **331** of the engine **300**, and vertically toward the bottom surface **612** of the oil pan **310**. Fourth arm **400** extends in a fourth direction **610** away from the central axis **343**, toward the rear end **331** of the engine **300**, and vertically away from the bottom surface **612**, toward the engine block **313**.

[0061] By positioning the arms in this way, the first electric motor **306** is coupled to the oil pan **310** across an increased length **602** and an increased height **603** of the oil pan **310** (with the length **602** in the direction of the longitudinal axis **324**, and with the height **603** in the vertical direction indicated by the z-axis of reference axes **299**). This configuration increases a sturdiness and stability of the coupling of the first electric motor **306** to the oil pan **310**. For example, during conditions in which the first electric motor **306** is energized (e.g., via a battery such as battery **58** and/or a starter/generator such as integrated starter/generator **181** described above with reference to FIGS. **1-2**) in order to provide torque to a front wheel of the vehicle (e.g., first front wheel **167** described above), the coupling of the first electric motor **306** to the oil pan **310** across the increased length **602** and increased height **603** of the first exterior surface **307** of the oil pan **310** via the arms retains the first electric motor **306** in its position relative to the oil pan **310** and prevents the housing **345** of the first electric motor **306** from rotating relative to the oil pan **310** and engine **300**.

[0062] The first arm **316**, second arm **312**, third arm **320**, and fourth arm **400** each include an axial extension positioned to align with a respective mounting boss of the oil pan **310** (as described further below). For example, the first arm **316** includes a first axial extension **351**, the second arm **312** includes a second axial extension **355**, the third arm **320** includes a third axial extension **349**, and the fourth arm **400** includes a fourth axial extension **700** (shown by FIG. **7**). Each axial extension extends away from its respective arm in an axial direction of the first electric motor **306** (e.g., a direction parallel to the central axis **343** of the cylindrical section **339**, and toward the oil pan **310**). Each axial extension includes a central opening (e.g., a passage) positioned to align with an opening of a mounting boss of the oil pan **310**. For example, first axial extension **351** includes first opening **353** positioned to align with an opening of a first mounting boss **371**, second axial extension **355** includes second opening **357** positioned to align with an opening of a second mounting boss **373**, third axial extension **349** includes third opening **359** positioned to align with an opening of a third mounting boss **375**, and fourth axial extension **700** includes fourth opening **406** (shown by FIG. **4**) positioned to align with an opening of a fourth mounting boss **702** (shown by FIG. **7**). In some examples, a fastener (e.g., a bolt) may be inserted through the opening of each axial extension and into the corresponding opening of the respective mounting bosses in order to couple the housing **345** of the first electric motor **306** to the first exterior surface

307 of the oil pan 310. In other examples, the axial extensions may be coupled to the mounting bosses in a different way (e.g., clamped, welded, etc.). In yet other examples, the housing 345 of the first electric motor 306 may include a different number and/or arrangement of axial extensions and/or arms, and in other examples, the housing 345 may not include the axial extensions and/or the arms. For example, the housing 345 may include one or more openings formed by the cylindrical section 339 and positioned to align with respective mounting bosses of the oil pan 310 in order to couple the housing 345 to the first exterior surface 307 (e.g., via fasteners inserted through the openings and into the mounting bosses).

[0063] Although the first electric motor 306 coupled to the first exterior surface 307 is described above as an example, the second electric motor 308 may be coupled to the second exterior surface 309 of the oil pan 310 in a similar way (e.g., via a plurality of arms having axial extensions coupled to mounting bosses of the oil pan 310, such as axial extension 319 of arm 318 coupled to mounting boss 321 as shown by FIG. 3 and FIG. 5, and axial extension 315 of arm 314 coupled to mounting boss 323 as shown by FIG. 3).

[0064] First electric motor 306 is directly coupled to a first reduction gearbox 302, and second electric motor 308 is directly coupled to a second reduction gearbox 304. Said another way, first electric motor 306 is coupled to first reduction gearbox 302 without any additional components positioned between the first electric motor 306 and the first reduction gearbox 302, and the second electric motor 308 is coupled to the second reduction gearbox 304 without any additional components positioned between the second electric motor 308 and the second reduction gearbox 304. In one example, the housing 345 of first electric motor 306 may be directly coupled with the first reduction gearbox 302 such that the housing 345 may share one or more common surfaces with the first reduction gearbox 302 and/or surfaces of the housing 345 may be in face-sharing contact with surfaces of the first reduction gearbox 302. The second electric motor 308 may be coupled to the second reduction gearbox 304 in a similar way.

[0065] A torque produced by the first electric motor 306 (e.g., via energization of the first electric motor 306 by a controller of the engine 300, similar to controller 12 described above with reference to FIGS. 1-2) is converted into a rotational motion of a first front axle of the vehicle (e.g., first front axle 208 described above with reference to FIG. 2) by the first reduction gearbox 302. In one example, torque applied to an input shaft of the first reduction gearbox 302 by the first electric motor 306 may result in a rotation of the input shaft at a first speed. Rotating the input shaft at the first speed may rotate a plurality of gears within the first reduction gearbox 302, and the rotation of the gears may apply a torque to the first axle to rotate the first axle at a second speed.

[0066] In some examples, a gear ratio of the first reduction gearbox 302 may be adjusted via electrical signals transmitted to the first reduction gearbox 302 by the controller. Adjusting the gear ratio may adjust the rotational speed of the first axle (e.g., rotating at the second speed) relative to the rotational speed of the input shaft (e.g., rotating at the first speed). In one example, increasing the gear ratio may reduce the rotational speed of the first axle relative to the rotational speed of the input shaft, and decreasing the gear ratio may increase the rotational speed of the first axle relative to the rotational speed of the input shaft.

[0067] Although operation of the first electric motor 306 and first reduction gearbox 302 are described above as an example, the second electric motor 308 and second reduction gearbox 304 may operate in a similar way (e.g., with a torque produced by the second electric motor 308 against an input shaft of the second reduction gearbox 304 being converted into a rotational motion of a second front axle coupled to the second reduction gearbox 304, similar to second front axle 206 described above with reference to FIG. 2).

[0068] The first electric motor 306 and the second electric motor 308 may each be pancake motors having a diameter in a radial direction relative to the mounting axis 322 greater than a width in a direction parallel to the mounting axis 322. For example, the cylindrical section 339 of the first electric motor 306 may have a diameter 404 (shown by FIG. 4) and the width 328, with the diameter 404 being a greater amount of length than the width 328. Similarly, a diameter of the cylindrical section 341 of the second electric motor 308 may be greater than a width 326 of the cylindrical section 341.

[0069] In this configuration, an amount of space occupied by the first electric motor 306 and the second electric motor 308 within an engine compartment of the vehicle may be reduced. However, in other examples, the first electric motor 306 and/or second electric motor 308 may have a different shape (e.g., a different width and/or diameter) than the electric motors in the example shown by FIGS. 3-7. For example, the width of the cylindrical section of the first electric motor 306 may be greater than the diameter of the cylindrical section of the first electric motor 306, the width of the cylindrical section of the second electric motor 308 may be greater than the diameter of the cylindrical section of the second electric motor 308, one or both of the first electric motor and the second electric motor may have a non-cylindrical shape (e.g., rectangular), etc. However, in each example, the first electric motor 306 is directly coupled to the first exterior surface 307 and the second electric motor 308 is directly coupled to the second exterior surface 309 as described above.

[0070] In some examples, one or more engine mounts may be coupled to the engine block 313 in order to couple the engine 300 to a frame of the vehicle (e.g., frame 218 described above with reference to FIG. 2). For example, a first engine mount 500 (shown by FIGS. 5-7) may be directly coupled to the engine block 313 (e.g., via a plurality of fasteners, such as bolts) at the first side 334, and a second engine mount 704 (shown by FIG. 7) may be directly coupled to the engine block 313 at the second side 336. The first engine mount 500 and second engine mount 704 may be hydraulically actuated devices configured to increase an amount of damping of the engine (e.g., reduce an amount of vibrational motions transferred from the engine to the frame and/or to other components of the vehicle).

[0071] In other to further couple the electric motors to the engine 300, the first electric motor 306 and/or second electric motor 308 may include one or more angled arms shaped to couple with the engine mounts described above. For example, FIGS. 5-6 show an angled arm 502 of the housing 345 of the first electric motor 306 extending in a direction away from the central axis 343 of the cylindrical section 339 and away from the mounting axis 322 to couple with the first engine mount 500. Specifically, the angled arm

502 is positioned such that an aperture 503 formed by the angled arm 502 is aligned with a corresponding mounting feature 600 (shown partially by FIG. 6) of the engine mount 500. In some examples, the angled arm 502 may be coupled to the first engine mount 500 via a fastener (e.g., a bolt) inserted into both of the aperture 503 and the mounting feature 600, with the mounting feature 600 being an aperture formed by an exterior surface of the first engine mount 500. In other examples, the housing 345 of the first electric motor 306 may not be coupled to the first engine mount 500, or the housing 345 may be coupled to the first engine mount 500 in a different way (e.g., clamped, welded, etc.).

[0072] The second electric motor **308** may include an angled arm similar to the angled arm **502**, and the angled arm of the second electric motor **308** may be coupled to the second engine mount **704** in a similar way (e.g., as described with reference to the first electric motor **306** coupled to first engine mount **500** by angled arm **502**). In other examples, the second electric motor **308** may not be coupled to the second engine mount **704**, or the angled arm of the second electric motor **308** may be coupled to the second engine mount **704** in a different way (e.g., clamped, welded, etc.). By coupling the first electric motor **306** to the first engine mount **500** via the angled arm **502**, the first electric motor **306** may be more securely coupled to the engine **300**. Similarly, coupling the second electric motor **308** to the second engine mount **704** as described above may more securely couple the second electric motor **308** to the engine **300**.

[0073] FIGS. **3-7** show example configurations with relative positioning of the various components. If shown directly contacting each other, or directly coupled, then such elements may be referred to as directly contacting or directly coupled, respectively, at least in one example. Similarly, elements shown contiguous or adjacent to one another may be contiguous or adjacent to each other, respectively, at least in one example. As an example, components laying in face-sharing contact with each other may be referred to as in face-sharing contact. As another example, elements positioned apart from each other with only a space there-between and no other components may be referred to as such, in at least one example. As yet another example, elements shown above/below one another, at opposite sides to one another, or to the left/right of one another may be referred to as such, relative to one another. Further, as shown in the figures, a topmost element or point of element may be referred to as a "top" of the component and a bottommost element or point of the element may be referred to as a "bottom" of the component, in at least one example. As used herein, top/bottom, upper/lower, above/below, may be relative to a vertical axis of the figures and used to describe positioning of elements of the figures relative to one another. As such, elements shown above other elements are positioned vertically above the other elements, in one example. As yet another example, shapes of the elements depicted within the figures may be referred to as having those shapes (e.g., such as being circular, straight, planar, curved, rounded, chamfered, angled, or the like). Further, elements shown intersecting one another may be referred to as intersecting elements or intersecting one another, in at least one example. Further still, an element shown within another element or shown outside of another element may be referred as such, in one example.

[0074] In this way, by coupling the first electric motor and the second electric motor directly to the engine (e.g., to the oil pan), the vehicle is provided with a front-wheel drive system that occupies a decreased amount of space. The shorter axial width of the electric motors relative to the diameter of the electric motors enables each electric motor to be positioned between a respective reduction gearbox and the exterior surfaces of the engine, thereby decreasing an overall size of the front-wheel drive system. Coupling the electric motors directly to the engine via the arms and axial extensions further secures each electric motor into its corresponding position with respect to the engine. The arms of each electric motor extend in different directions to increase the length and height of an area at which each electric motor couples to the oil pan, thereby increasing a stability of each electric motor relative to the oil pan and preventing each electric motor from rotating relative to the engine. Additionally, by including the integrated starter/generator, the electric motors may be supplied electrical energy by the starter/generator during operation of the engine. The technical effect of energizing the electric motors via the starter/generator is to enable the electric motors to drive the front wheels of the vehicle during a wider variety of engine operating conditions.

[0075] As one embodiment, a system comprises: a longitudinally mounted engine adapted to drive rear wheels of a vehicle; and two, independent, electric motors mounted to the engine, on opposite sides of the engine, and adapted to drive front wheels of the vehicle, where the two electric motors are not rotationally coupled to the engine. In a first example of the system, the two electric motors each include a housing having a cylindrical section, and a width of the cylindrical section in a direction of a central axis of the cylindrical section and a latitudinal axis of the engine is less than a diameter of the cylindrical section. A second example of the system optionally includes the first example, and further includes wherein the two electric motors each include a plurality of arms extending in different outward directions from a housing of each electric motor, and wherein the plurality of arms mount the electric motors to the engine. A third example of the system optionally includes one or both of the first and second examples, and further includes wherein the two electric motors include a first electric motor mounted to an oil pan of the engine at a first side of the engine and a second electric motor mounted to the oil pan at a second side of the engine, with the first side being opposite to the second side relative to a longitudinal axis of the engine. A fourth example of the system optionally includes one or more or each of the first through third examples, and further includes wherein the oil pan is positioned along a longitudinal axis of the vehicle and a central vertical axis of the engine. A fifth example of the system optionally includes one or more or each of the first through fourth examples, and further includes wherein the oil pan includes a first plurality of mounting bosses formed by a first exterior surface at the first side and a second plurality of mounting bosses formed by a second exterior surface at the second side. A sixth example of the system optionally includes one or more or each of the first through fifth examples, and further includes wherein the first electric motor is coupled to the first plurality of mounting bosses and the second electric motor is coupled to the second plurality of mounting bosses. A seventh example of the system optionally includes one or more or each of the first through sixth examples, and further includes wherein the two electric motors include a first electric motor and a second electric motor, wherein a first reduction gearbox is coupled to the first electric motor between an output of the first electric motor and a first front axle shaft, and wherein a second reduction gearbox is coupled to the second electric motor between an output of the second electric motor and a second front axle shaft. An eighth example of the system optionally includes one or more or each of the first through seventh examples, and further includes wherein a length from a first end of the crankshaft to a second end of the crankshaft is positioned parallel to a longitudinal axis of the vehicle. A ninth example of the system optionally includes one or more or each of the first through eighth examples, and further includes an integrated starter motor/generator mechanically coupled to a crankshaft of the engine and electrically coupled to the two electric motors. A tenth example of the system optionally includes one or more or each of the first through ninth examples, and further includes a plurality of engine mounts coupling the engine to a frame of the vehicle, with each electric motor of the two electric motors coupled to a different engine mount of the plurality of engine mounts.

[0076] As another embodiment, a system comprises: twin, independent, electric motors mounted to either side of an exterior of an oil pan of a longitudinally mounted engine in a rear wheel drive vehicle; and twin reduction gearboxes, each reduction gearbox of the twin reduction gearboxes positioned between an output of one of the twin electric motors and one of two front axle shafts of front wheels of the rear wheel drive vehicle. In a first example of the system, the engine is mechanically coupled to rear wheels of the vehicle by a crankshaft of the engine, and the engine is not mechanically coupled to front wheels of the vehicle by the crankshaft. A second example of the system optionally includes the first example, and further includes a transmission coupled to the crankshaft of the engine, the transmission positioned along a longitudinal axis of the vehicle at a rear end of the engine. A third example of the system optionally includes one or both of the first and second examples, and further includes wherein the engine is a V-engine including two opposing cylinder banks, and wherein the electric motors are mounted to the exterior of the oil pan vertically below the cylinder banks relative to a surface on which the vehicle sits.

[0077] As another embodiment, a vehicle comprises: an engine including an engine block and an oil pan mounted to the engine block; two rear wheels driven by the engine; two front wheels not rotationally coupled to the engine; two, independent, electric motors, where each motor of the two electric motors drives a different one of the two front wheels and is coupled to an opposite, different side of each of the oil pan and the engine block; and two reduction gearboxes, each reduction gearbox coupled between and to each of an output of one of the two electric motors and one of the two front wheels. In a first example of the vehicle, each electric motor of the two electric motors includes a first plurality of arms extending in an outward direction away from a central axis of a cylindrical section of a housing of each electric motor. A second example of the vehicle optionally includes the first example, and further includes wherein each arm of the first plurality of arms includes an axial extension coupling the housing of each electric motor to the oil pan. A third example of the vehicle optionally includes one or both of the first and second examples, and further includes wherein each electric motor includes a second plurality of arms coupling the housing of each electric motor to engine mounts of the engine. A fourth example of the vehicle optionally includes one or more or each of the first through third examples, and further includes wherein each arm of the first plurality of arms extends across a length of the oil pan in a direction of a longitudinal axis of the engine and a height of the oil pan in a vertical direction relative to a ground surface on which the vehicle sits, and wherein each arm of the second plurality of arms extends in the vertical direction and is coupled to an engine mount of the engine.

[0078] In another representation, a system comprises: a longitudinally mounted engine adapted to drive rear wheels of a vehicle; an electric machine adapted to drive the rear wheels, the electric machine and engine selectably coupled to the rear wheels by a plurality of clutches; and two, independent, electric motors mounted to the engine, on opposite sides of the engine, and adapted to drive front wheels of the vehicle, where the two electric motors are not rotationally coupled to the engine.

[0079] Note that the example control and estimation routines included herein can be used with various engine and/or vehicle system configurations. The control methods and routines disclosed herein may be stored as executable instructions in non-transitory memory and may be carried out by the control system including the controller in combination with the various sensors, actuators, and other engine hardware. The specific routines described herein may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As such, various actions, operations, and/or functions illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of processing is not necessarily required to achieve the features and advantages of the example embodiments described herein, but is provided for ease of illustration and description. One or more of the illustrated actions, operations and/or functions may be repeatedly performed depending on the particular strategy being used. Further, the described actions, operations and/or functions may graphically represent code to be programmed into non-transitory memory of the computer readable storage medium in the engine control system, where the described actions are carried out by executing the instructions in a system including the various engine hardware components in combination with the electronic controller.

[0080] It will be appreciated that the configurations and routines disclosed herein are exemplary in nature, and that these specific embodiments are not to be considered in a limiting sense, because numerous variations are possible. For example, the above technology can be applied to V-6, I-4, I-6, V-12, opposed 4, and other engine types. The subject matter of the present disclosure includes all novel and non-obvious combinations and sub-combinations of the various systems and configurations, and other features, functions, and/or properties disclosed herein.

[0081] The following claims particularly point out certain combinations and sub-combinations regarded as novel and non-obvious. These claims may refer to "an" element or "a first" element or the equivalent thereof. Such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements. Other combinations and sub-combinations of the disclosed features, functions, elements, and/or properties may be claimed through amendment of the present claims or through presentation of new claims in this or a related application. Such claims, whether broader, narrower, equal, or different in scope to the original claims, also are regarded as included within the subject matter of the present disclosure.

1. A system, comprising:
a longitudinally mounted engine adapted to drive rear wheels of a vehicle; and
two, independent, electric motors mounted to the engine, on opposite sides of the engine, and adapted to drive front wheels of the vehicle, where the two electric motors are not rotationally coupled to the engine.

2. The system of claim **1**, wherein the two electric motors each include a housing having a cylindrical section, and wherein a width of the cylindrical section in a direction of a central axis of the cylindrical section and a latitudinal axis of the engine is less than a diameter of the cylindrical section.

3. The system of claim **1**, wherein the two electric motors each include a plurality of arms extending in different outward directions from a housing of each electric motor, and wherein the plurality of arms mount the electric motors to the engine.

4. The system of claim **1**, wherein the two electric motors include a first electric motor mounted to an oil pan of the engine at a first side of the engine and a second electric motor mounted to the oil pan at a second side of the engine, with the first side being opposite to the second side relative to a longitudinal axis of the engine.

5. The system of claim **4**, wherein the oil pan is positioned along a longitudinal axis of the vehicle and a central vertical axis of the engine.

6. The system of claim **4**, wherein the oil pan includes a first plurality of mounting bosses formed by a first exterior surface at the first side and a second plurality of mounting bosses formed by a second exterior surface at the second side.

7. The system of claim **6**, wherein the first electric motor is coupled to the first plurality of mounting bosses and the second electric motor is coupled to the second plurality of mounting bosses.

8. The system of claim **1**, wherein the two electric motors include a first electric motor and a second electric motor, wherein a first reduction gearbox is coupled to the first electric motor between an output of the first electric motor and a first front axle shaft, and wherein a second reduction gearbox is coupled to the second electric motor between an output of the second electric motor and a second front axle shaft.

9. The system of claim **8**, wherein a length from a first end of the crankshaft to a second end of the crankshaft is positioned parallel to a longitudinal axis of the vehicle.

10. The system of claim **1**, further comprising an integrated starter motor/generator mechanically coupled to a crankshaft of the engine and electrically coupled to the two electric motors.

11. The system of claim **1**, further comprising a plurality of engine mounts coupling the engine to a frame of the vehicle, with each electric motor of the two electric motors coupled to a different engine mount of the plurality of engine mounts.

12. A system, comprising:
twin, independent, electric motors mounted to either side of an exterior of an oil pan of a longitudinally mounted engine in a rear wheel drive vehicle; and
twin reduction gearboxes, each reduction gearbox of the twin reduction gearboxes positioned between an output of one of the twin electric motors and one of two front axle shafts of front wheels of the rear wheel drive vehicle.

13. The system of claim **12**, wherein the engine is mechanically coupled to rear wheels of the vehicle by a crankshaft of the engine, and wherein the engine is not mechanically coupled to front wheels of the vehicle by the crankshaft.

14. The system of claim **13**, further comprising a transmission coupled to the crankshaft of the engine, the transmission positioned along a longitudinal axis of the vehicle at a rear end of the engine.

15. The system of claim **12**, wherein the engine is a V-engine including two opposing cylinder banks, and wherein the electric motors are mounted to the exterior of the oil pan vertically below the cylinder banks relative to a surface on which the vehicle sits.

16. A vehicle, comprising:
an engine including an engine block and an oil pan mounted to the engine block;
two rear wheels driven by the engine;
two front wheels not rotationally coupled to the engine;
two, independent, electric motors, where each motor of the two electric motors drives a different one of the two front wheels and is coupled to an opposite, different side of each of the oil pan and the engine block; and
two reduction gearboxes, each reduction gearbox coupled between and to each of an output of one of the two electric motors and one of the two front wheels.

17. The vehicle of claim **16**, wherein each electric motor of the two electric motors includes a first plurality of arms extending in an outward direction away from a central axis of a cylindrical section of a housing of each electric motor.

18. The vehicle of claim **17**, wherein each arm of the first plurality of arms includes an axial extension coupling the housing of each electric motor to the oil pan.

19. The vehicle of claim **18**, wherein each electric motor includes a second plurality of arms coupling the housing of each electric motor to engine mounts of the engine.

20. The vehicle of claim **19**, wherein each arm of the first plurality of arms extends across a length of the oil pan in a direction of a longitudinal axis of the engine and a height of the oil pan in a vertical direction relative to a ground surface on which the vehicle sits, and wherein each arm of the second plurality of arms extends in the vertical direction and is coupled to an engine mount of the engine.

* * * * *